# A High-Speed Spectroscopy System for Observing Lightning and Transient Luminous Events

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## Abstract

Here we present on a high-speed spectroscopy system that can be used to record atmospheric electrical discharges, including classic lightning and transient luminous events. The system consists a Phantom V1210 high-speed camera, a Volume Phase Holographic (VPH) grism, and the option for an optical slit. The spectrograph has the capability to record videos at speeds of 200,000 frames per second and has an effective wavelength band of 50-1000 nm for first order spectra. When combined with the slit, the system has a spectral resolution of about 0.25 nm per pixel. We have constructed a very durable enclosure made of aerospace grade Aluminum to house the high-speed spectrograph. It has two fans for continuous air flow, a removable tray to mount the spectrograph components, and a low-speed (30 frames per second) Watec camera attached to the top of it. A heavy duty Pelco pan/tilt motor is used to position the enclosure and can be controlled remotely through a Rasperry Pi computer.

An observation campaign has been conducted during the summers of 2017 and 2018 at the Florida Institute of Technology. Thus far, several cloud-to-ground discharges have been recorded at different frame rates and different exposures. The spectrum of a downward stepped leader and its return stroke will be reported on. Also, the spectra of another return stoke and images of a sprite will be presented.

## Spectrograph Components

- **System components:**
  - **- Phantom V1210 high speed camera**
    - - 12,000 fps at 1280 x 800 resolution
    - - up to 200,000 fps at reduced resolution
    - - 500 GB flash memory
  - **- Volume Phase Holographic grism**
    - - 1257 lines/mm (similar to Walker and Christian, 2017)
    - - Maximum efficiency for 550 to 775 nm, blazed at 630 nm
  - **- Lenses and slits**
    - - front lens (lens 1): 20 mm or 35 mm, wide angle
    - - collimating lens (lens 2): 85 mm
    - - camera lens (lens 3): 50 mm
    - - 50 or 100 micron slit
    - - resolution: 0.2 nm/pixel (slit), 0.3 nm/pixel (slitless)
- **Slit and front lens system can be removed for cloud-to-ground lightning**


Figure 1. Finished spectrograph system with enclosure, mounted on a heavy duty Pelco motor.

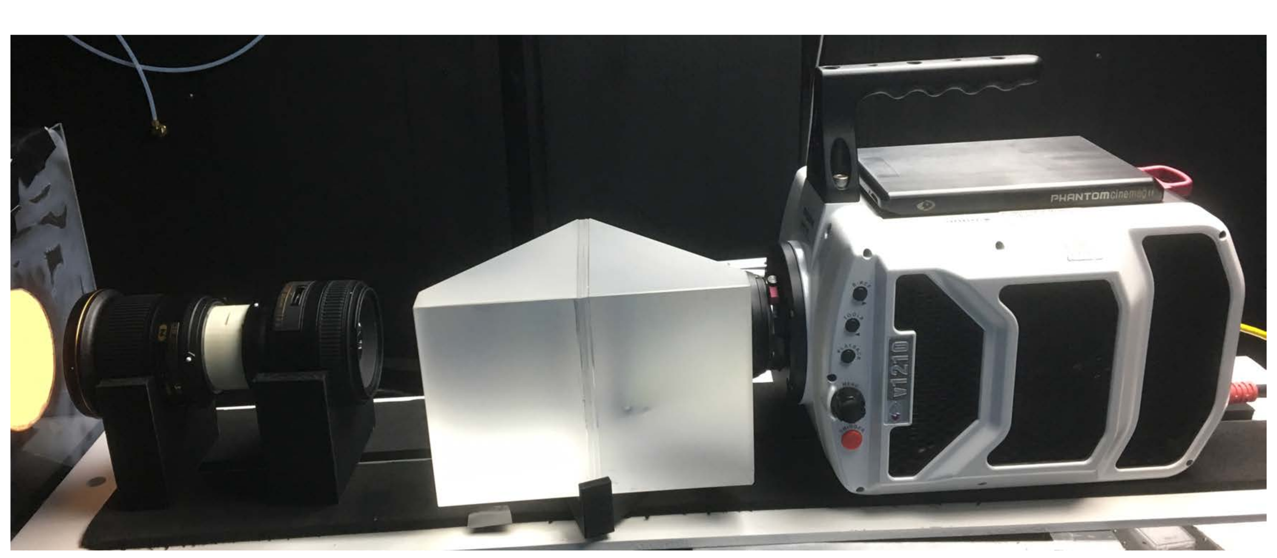

Figure 2. Phantom V1210 camera, grism, and front lens piece during a calibration.

## Observations

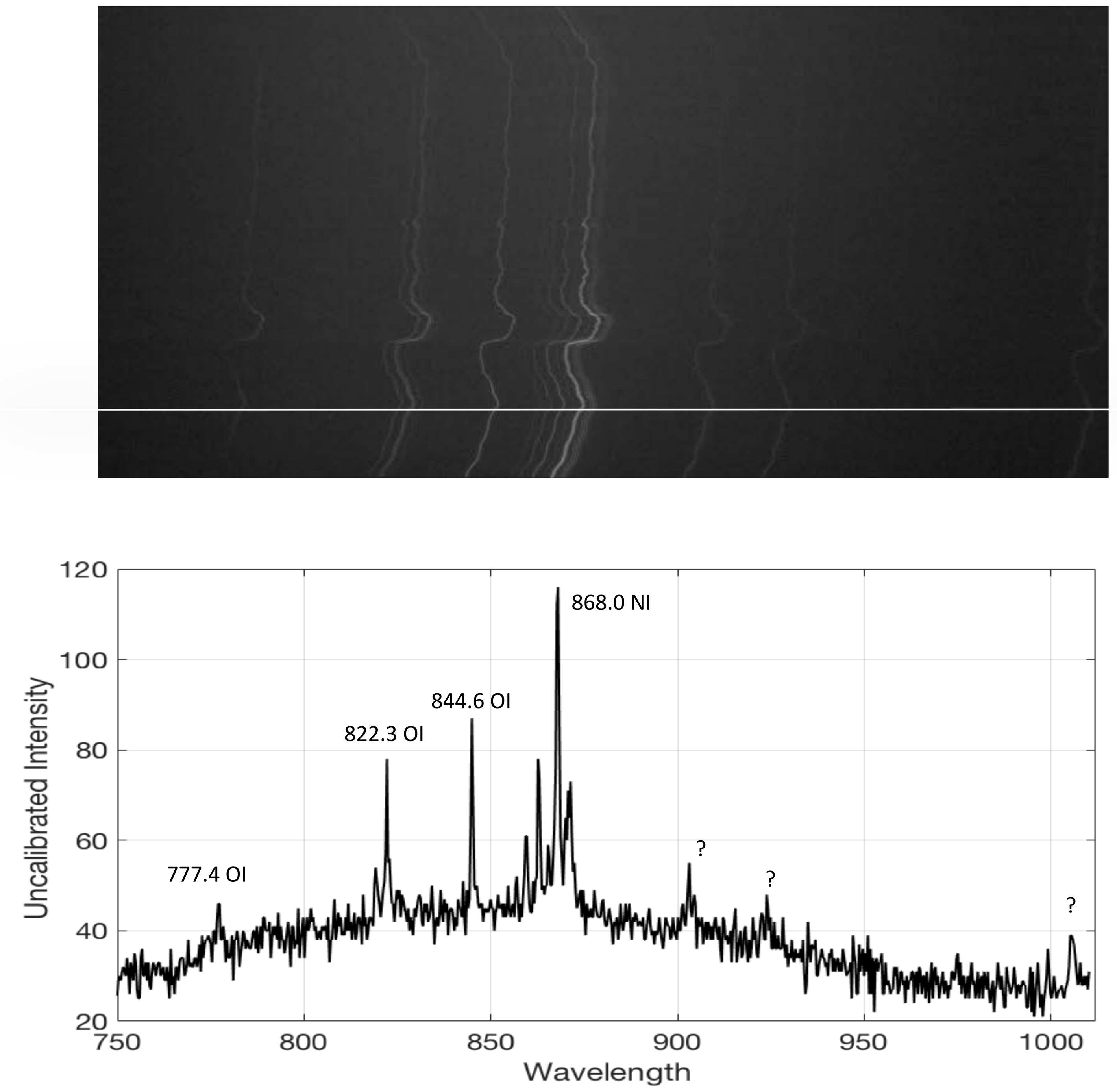


Figure 3. (Top) Recorded spectra of a downward lightning leader at 15,000 fps and 60 microsecond exposure. (Bottom) Spectra profile for the horizontal white line.

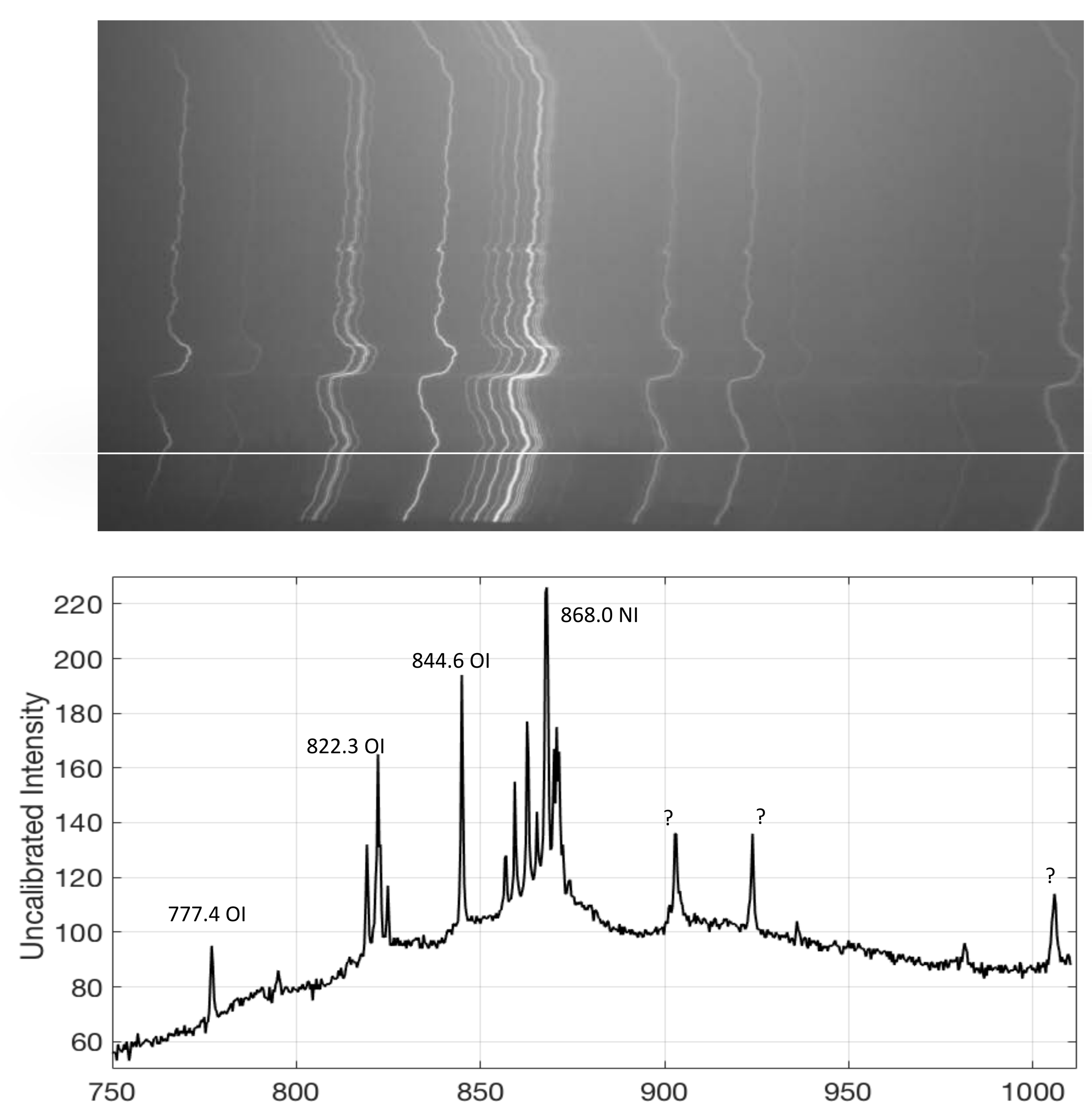


Figure 4. (Top) Recorded spectra for the return stroke of the flash in Figure 3. (Bottom) Spectra profile for the horizontal white line.

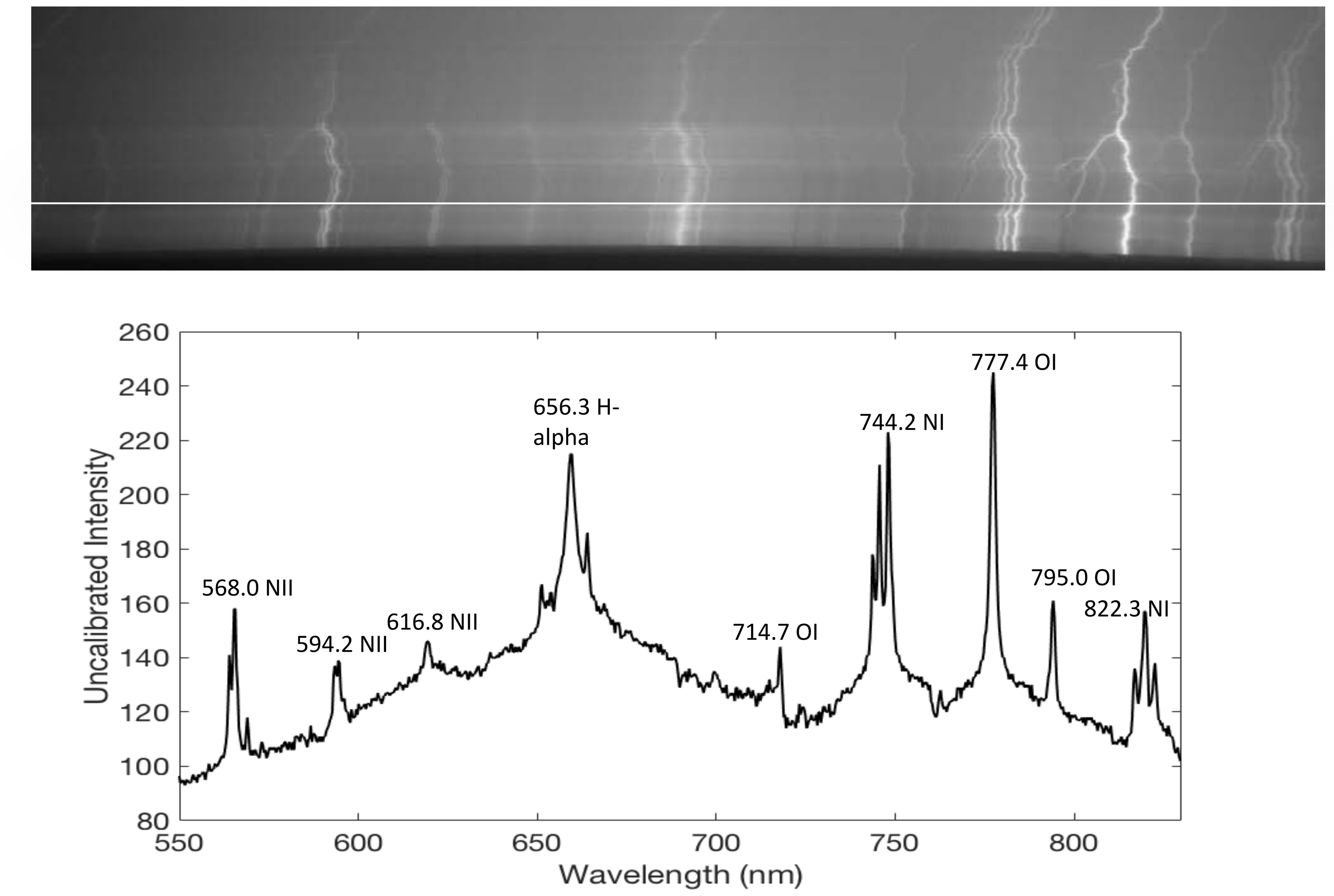


Figure 5. (Top) Recorded spectra of a return stroke at 15,000 fps and 60 microsecond exposure. (Bottom) Spectra profile for the horizontal white line.

Figure 6. (Left) Sprite recorded with no grism at 500 fps. (Right) Subsequent frame of the sprite from the left panel.

$$T = \frac{\epsilon_m - \epsilon_n}{k \ln\left(I_{nr} g_m A_{mp} \nu_{mp} / I_{mp} g_n A_{nr} \nu_{nr}\right)}.$$

Theoretical equation to estimate the temperature from the ratio of intensity from two spectral lines. The numerator is the difference in ionization energy, k is the Boltzmann constant, g is the degeneracy of the level, A is the Einstein coefficient, nu is the frequency associated with each respective intensity line. These are all constants and the the measured intensities (I) is from the recorded images.

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## References

Walker, T. D., and H. J. Christian (2017), Triggered lightning spectroscopy: Part 1. A qualitative analysis, *J. Geophys. Res. Atmos.*, *122*, 8000–8011, doi:10.1002/ 2016JD026419.